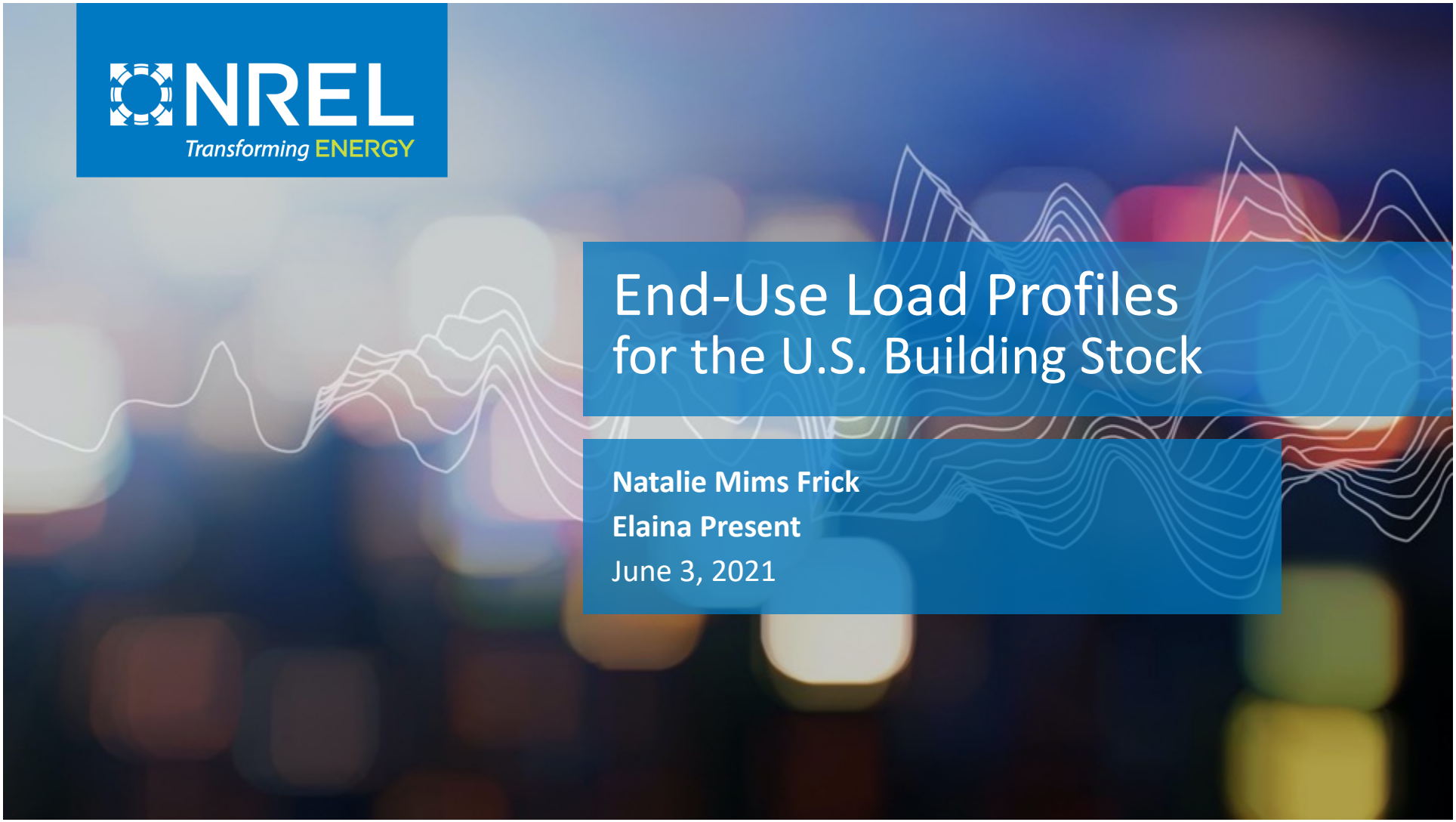


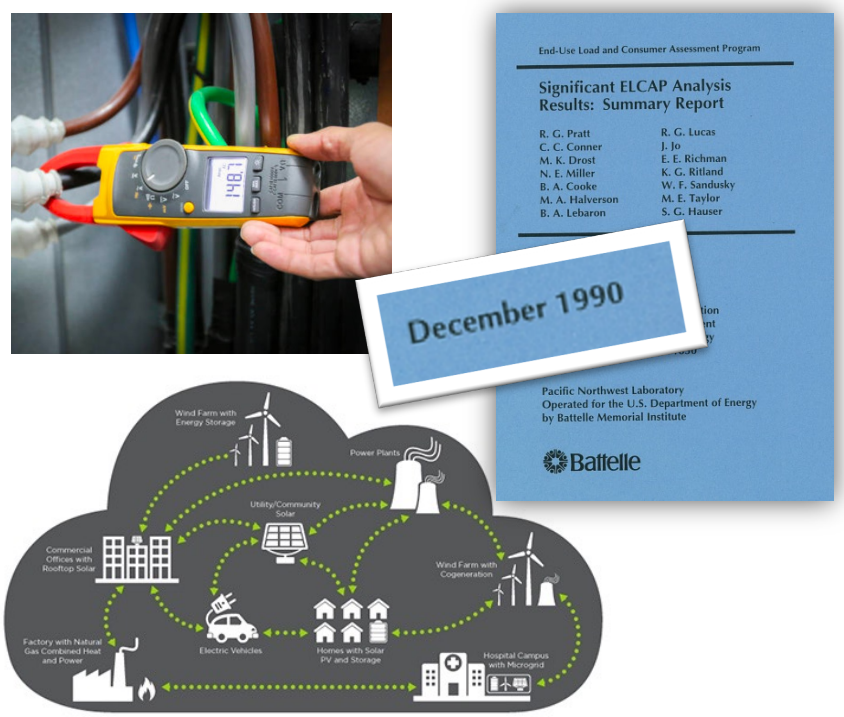
End-Use Load Profiles for the U.S. Building Stock

Natalie Mims Frick
Elaina Present
June 3, 2021

Project Overview and Deliverables

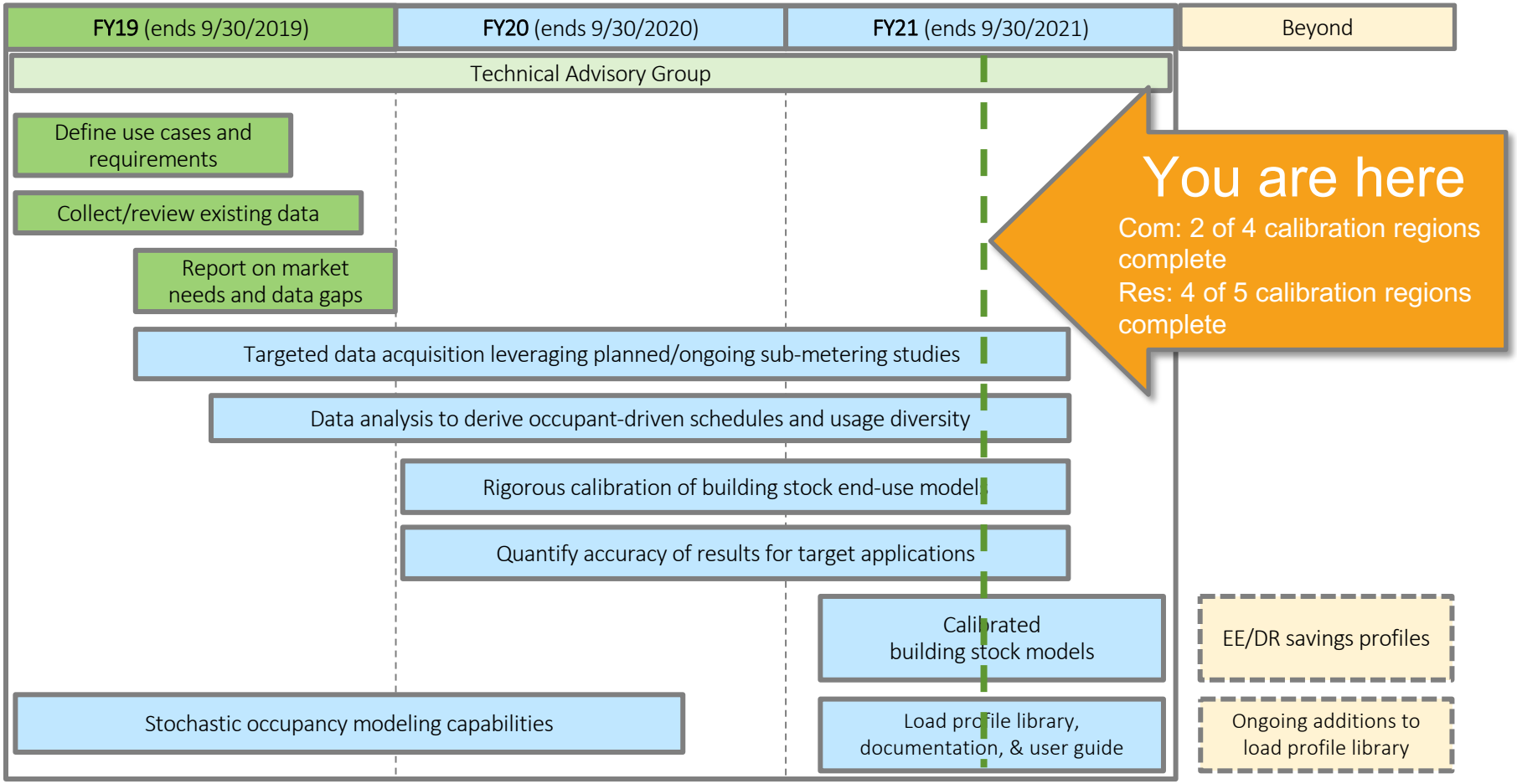
Existing End Use Load Profiles

- outdated
- limited to certain regions and building types because of the **high cost** of traditional sub-metering
- insufficient for accurate evaluation of numerous **emerging use cases**



Source: Navigant

Project Timeline



Major Efforts so Far

Overarching

- Year one report *End Use Load Profiles for the U.S. Building Stock: Market Needs, Use Cases and Data Gaps*
- Uncertainty quantification framework, defining “Quantities of Interest”

Residential

- End use transferability study
- Stochastic occupant behavior model
- 4 of 5 calibration regions

Commercial

- End use data sourcing
- AMI processing/outlier detection
- 2 of 4 calibration regions

Publication Plan

Public Datasets

- Published by Sept 30, 2021
- Web data viewer
- Pre-aggregated load profiles
- Raw individual building load profiles
- Raw individual building models
- Data access instructions

Public Webinar

- Conducted by Sept 30, 2021
- Presents project outcomes to technical advisory group and other stakeholders

Methodology and Results Report

- Published by Dec 31, 2021
- Detailed description of model improvements, validation, and uncertainty of results
- NREL lead

Applications and Opportunities Report

- Published by Dec 31, 2021
- Example applications and opportunities for using the dataset
- LBNL lead

To sign up for our mailing list and get occasional updates on all the above: https://www.nrel.gov/buildings/end-use-load-profiles.html

Resources

Publications

- Li et al. Characterizing Patterns and Variability of Building Electric Load Profiles in Time and Frequency Domain
- Bianchi et al. 2020. Modeling occupancy-driven building loads for large and diversified building stocks through the use of parametric schedules
- Parker et al. 2020. Framework for Extracting and Characterizing Load Profile Variability Based on a Comparative Study of Different Wavelet Functions
- Present et al. 2020. Putting our Industry's Data to Work: A Case Study of Large Scale Data Aggregation
- Northeast Energy Efificency Partnership (NEEP). 2020. Sharing Load Profile Data: Best Practices and Examples
- Frick et al. 2019. End-Use Load Profiles for the U.S. Building Stock: Market Needs, Use Cases, and Data Gaps
- N. Frick. 2019. End Use Load Profile Inventory
- E. Present and E. Wilson. 2019. End use load profiles for the U.S. Building Stock

Presentations and Slides

- Technical Advisory Group slides
  - LBNL and NREL site
- E. Present. 2021. IEPEC presentation.
- E. Wilson. 2020. EFX webinar
- E. Wilson. 2019. E Source interview
- E. Wilson. 2019. Peer Review presentation
- E. Present. 2019. NEEP presentation.

Software

- OpenStudio Occupant Variability Gem and Non Routine Variability Gem (more info at IBPSA newsletter)

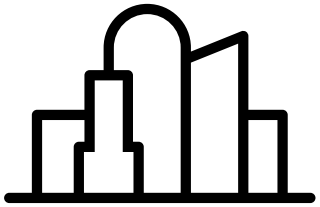
Data

- First year of 15-min NEEA HEMS data available: https://neea.org/data/end-use-load-research/energy-metering-study-data

A Few Details

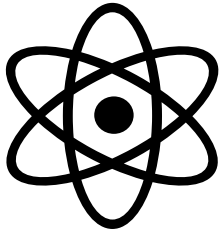
Project Outcomes | Calibrated Building Stock Models

ComStock ResStock



Building stock characteristics database

+



Physics-based computer modeling

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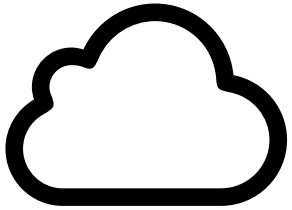


High-performance computing

- DOE-funded, NREL-developed models of the U.S. building stock
- 100,000s of statistically representative physics-based building energy models (BEM)
- Use DOE's BEM tools OpenStudio and EnergyPlus
- Produce hourly load profiles, but previous calibration has focused on annual energy consumption

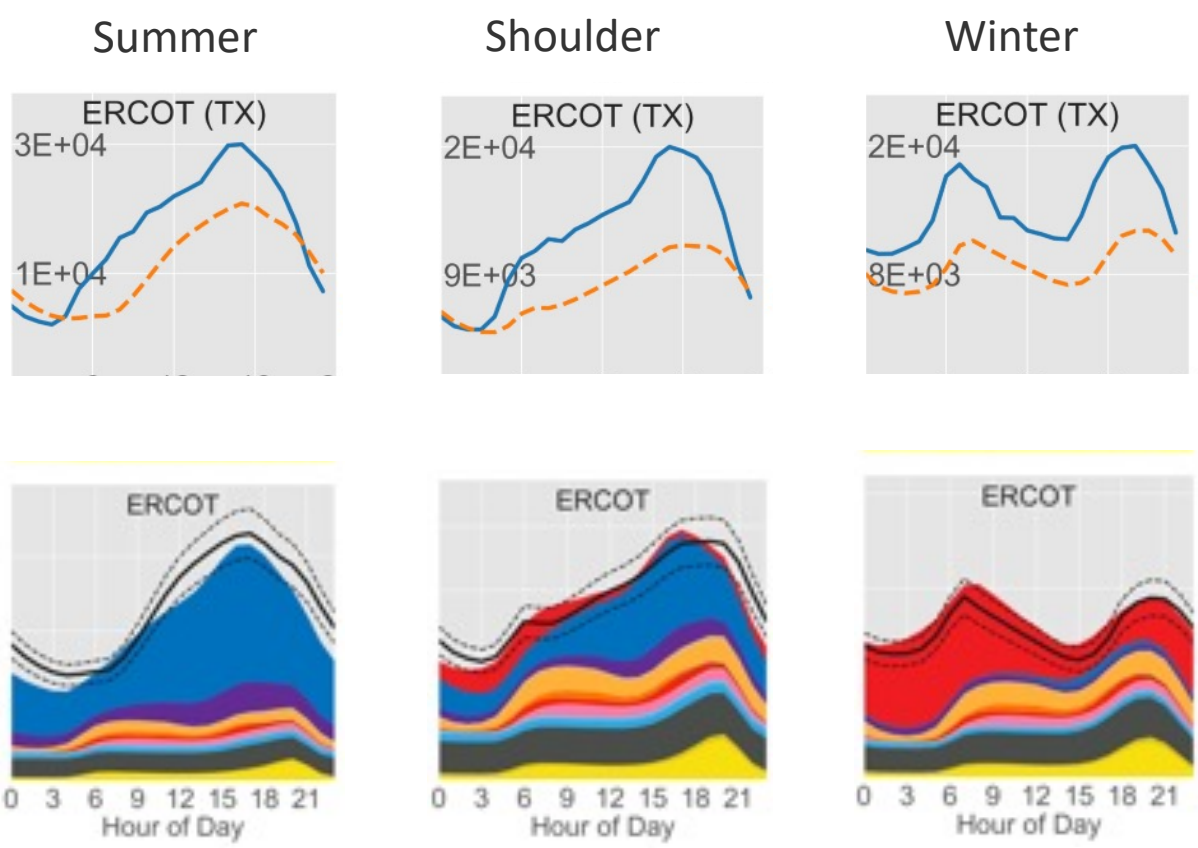
Guiding Principles

- We want to get the “why” right so we can ask questions about changes to the stock (i.e., savings load shapes)
- Make changes that are supported by data and domain experience, not simply to get a better fit
- Report out accuracy and uncertainty so users can decide if they want to use

Then and Now:
ERCOT Residential Load Profile Comparisons

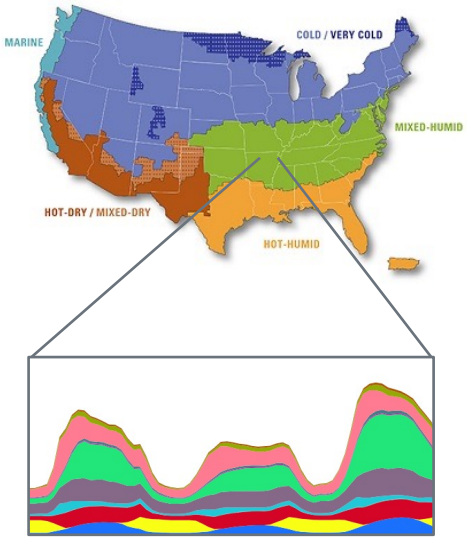
Before
End Use Load
Profiles Project

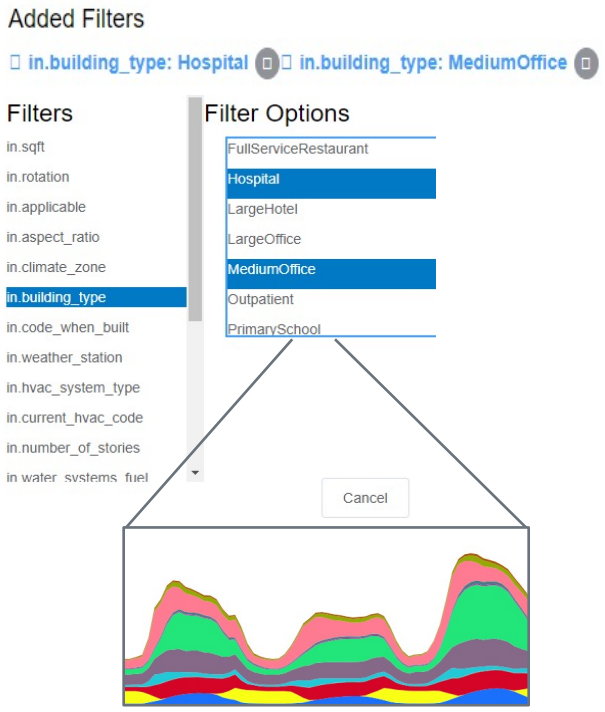
Current

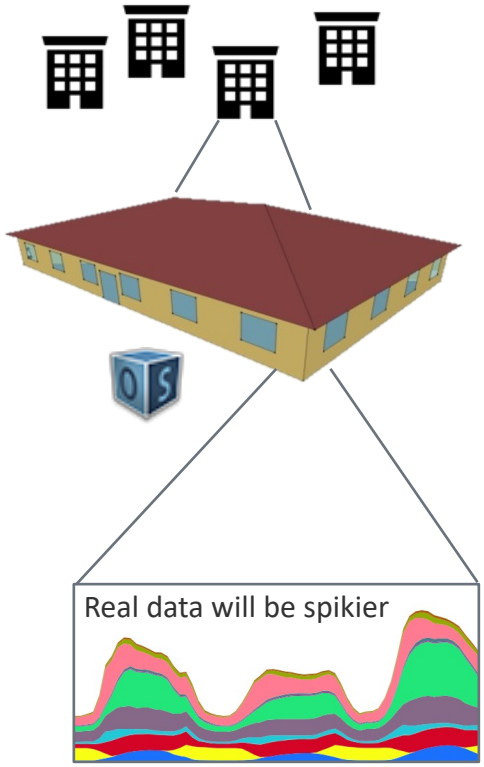


Same Data, Multiple Scales

Aggregates | Web Viewer | Individual Buildings





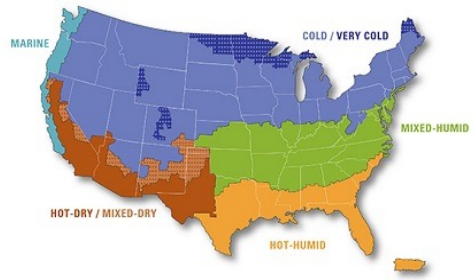


Pre-aggregated Load Profiles

Aggregates | Web Viewer | Individual Buildings

Pre-aggregated EULPs by building type for:

- U.S. States (contiguous)
- ASHRAE Climate Zones
- DOE Building America Climate Zones
- Electric System ISOs
- U.S. Census Public Use Microdata Area*
- U.S. Counties



Format:

- CSV files

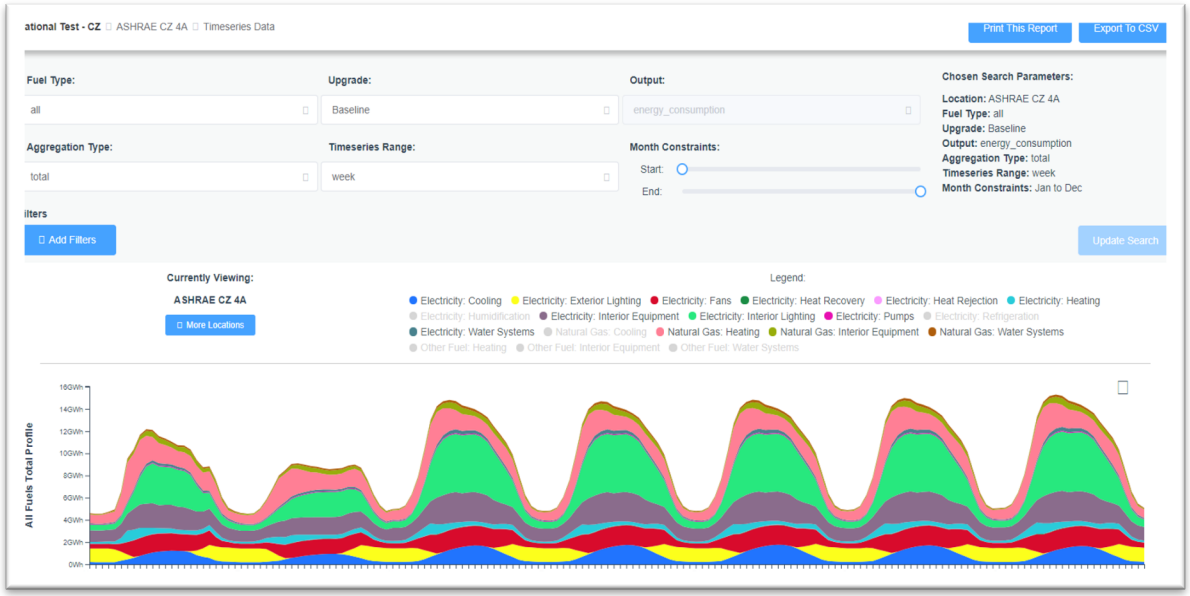
Additional Data:

- Count of models included per aggregation
- List of model IDs per aggregation
- Model characteristics by ID
- Timeseries mean, stdev, and range

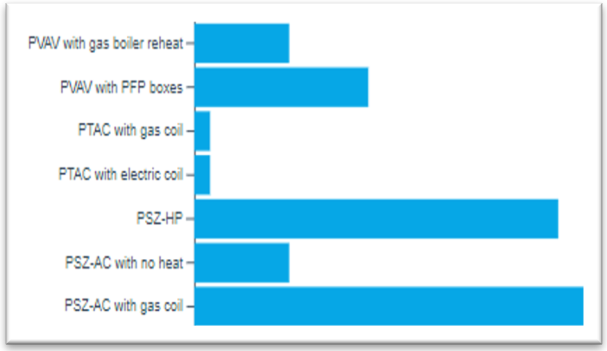
*PUMA is an area with ~200k people; ~2,400 in U.S.

Web Viewer Interface

Aggregates | Web Viewer | Individual Buildings



- View End Use Load Profiles
- View distributions of building characteristics
- Filter by building characteristic
- Filter by geography
- Select time window
- Download CSV of results



Individual Buildings – Load Profiles & Models

Aggregates | Web Viewer | Individual Buildings

Individual Building End Use Load Profiles

- ~450,000 residential
- ~350,000 commercial
- Full dataset will be 10's of terabytes
- Plan to include high-level instructions for loading this dataset using one cloud-based big-data analysis tool

Format:

- Folders with a series of Apache parquet* files
  - Likely 1 file per building, with IDs in names
- In Amazon S3 bucket or similar

Additional Data:

- Model characteristics by ID
- Model in OpenStudio (.osm) format

*https://parquet.apache.org/

Questions?

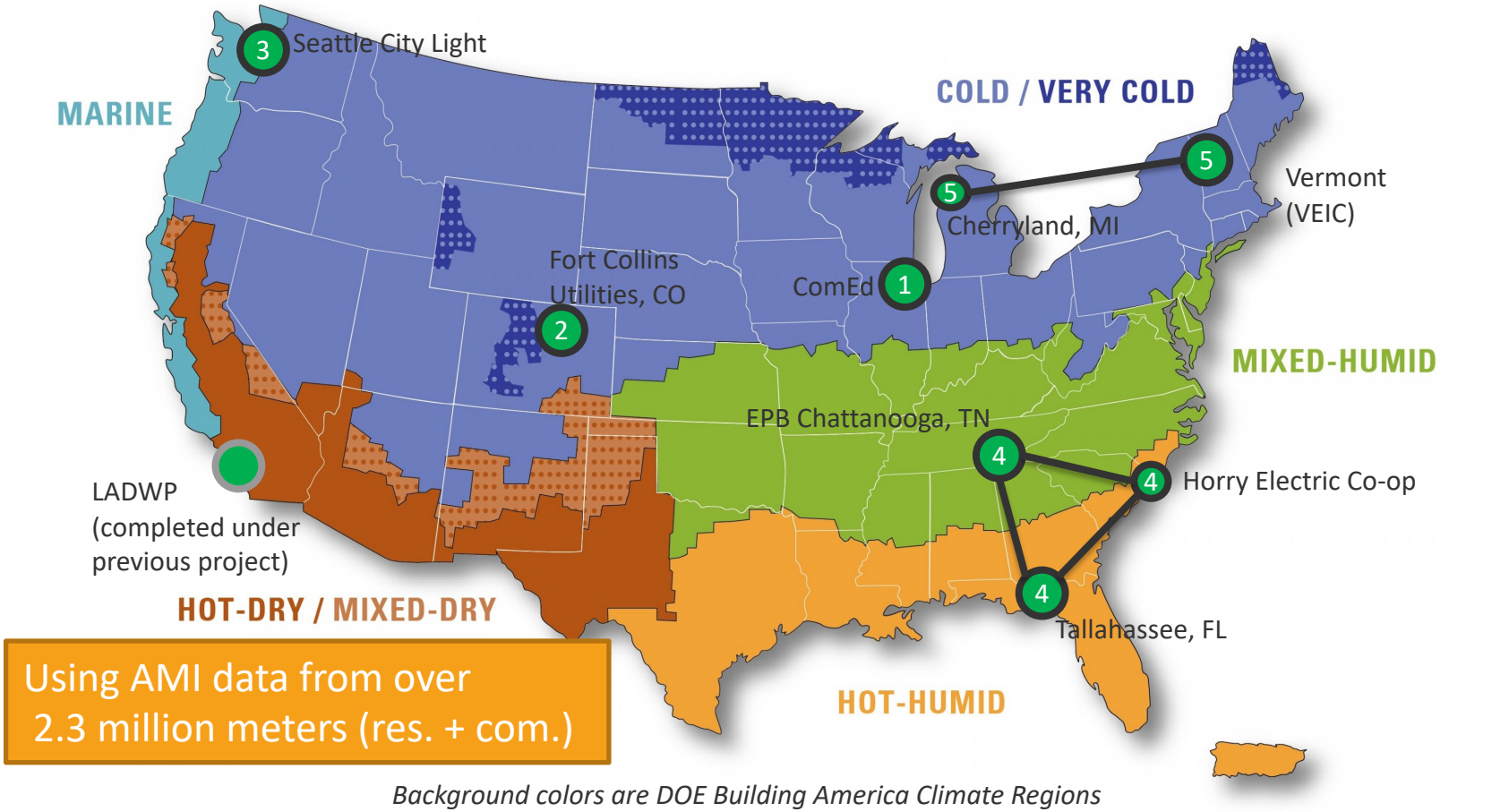
www.nrel.gov

https://www.nrel.gov/buildings/end-use-load-profiles.html

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Supplemental Slides

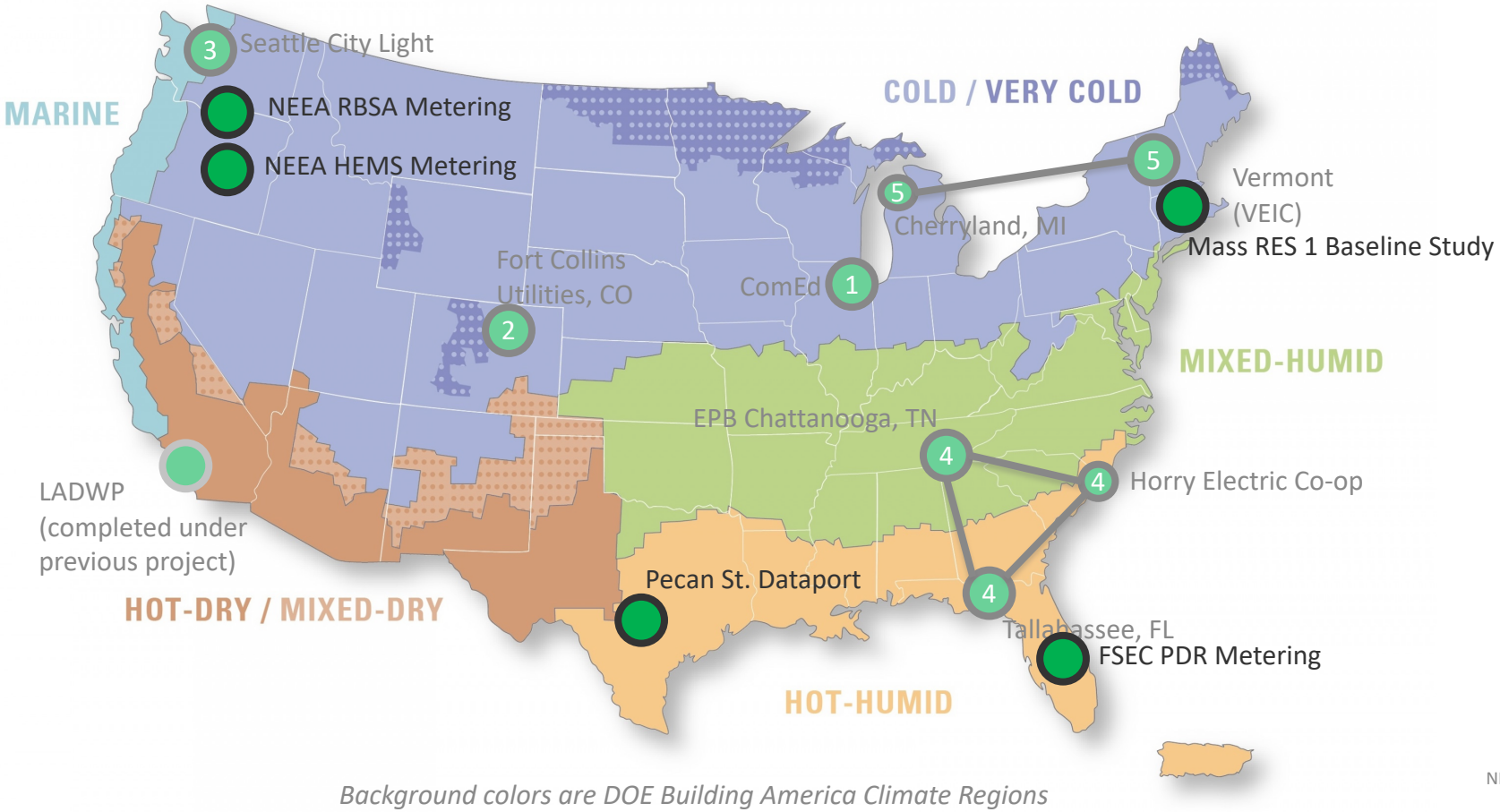
Summary of Residential AMI Calibration Regions



Using AMI data from over 2.3 million meters (res. + com.)

Background colors are DOE Building America Climate Regions

Summary of Residential Submeter Datasets

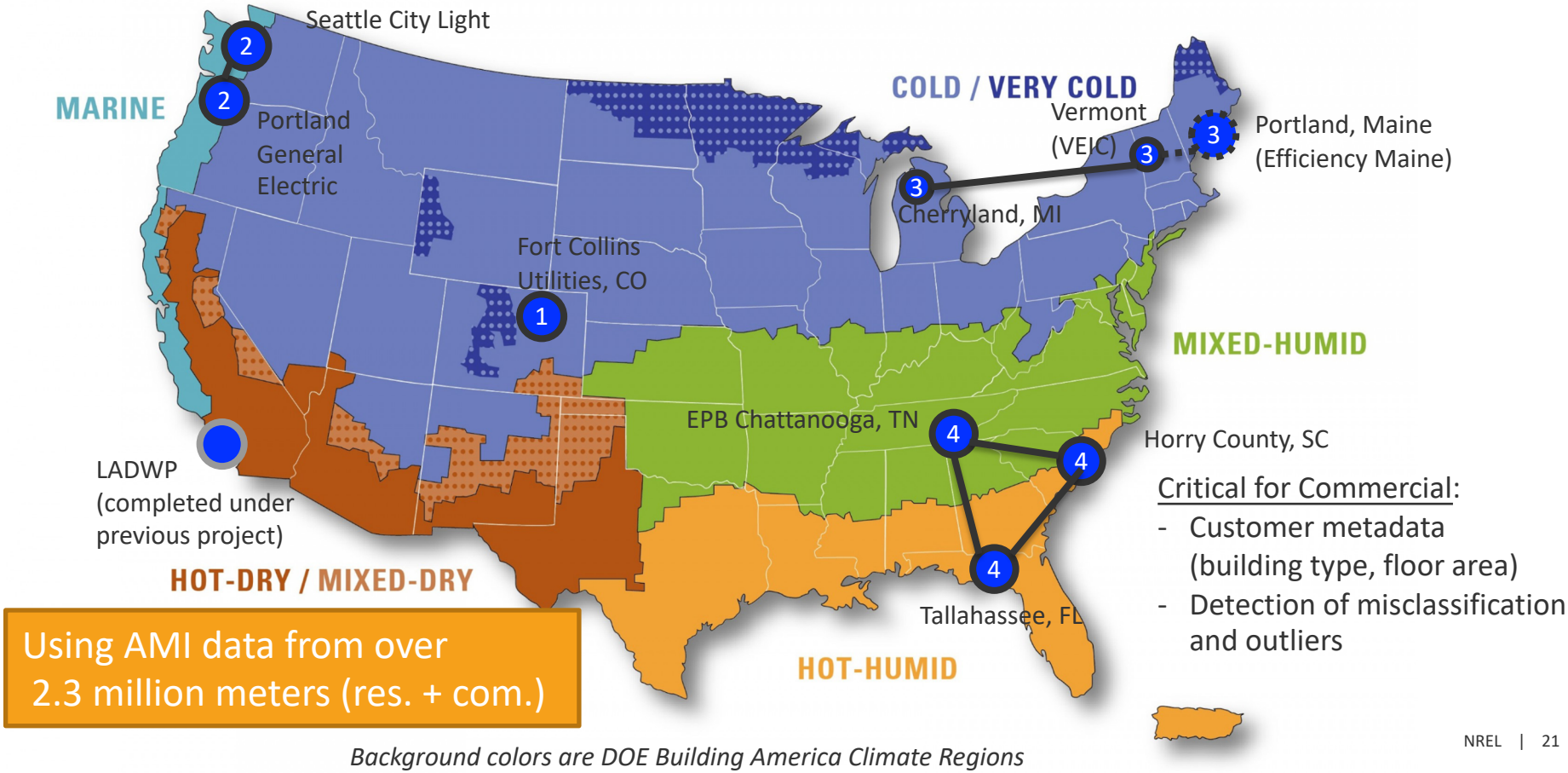


Background colors are DOE Building America Climate Regions

Residential Calibration

- Significant improvements seen across all truth data comparisons
- Remaining areas of focus include electric heating and heating/cooling behavior during shoulder seasons
- Our research found that appliance and plug load shapes are highly transferrable between regions
  - But the magnitudes are not; we incorporated data on how these end use magnitudes vary by region
- Region 5 of 5 to finish in July 2021

Summary of Commercial AMI Calibration Regions



Using AMI data from over 2.3 million meters (res. + com.)

Critical for Commercial:

- Customer metadata (building type, floor area)
- Detection of misclassification and outliers

Background colors are DOE Building America Climate Regions

Commercial Calibration

- Getting an accurate ground truth to use for calibration is challenging and critical
  - Submeter data not readily available, eventually procured from a range of companies
  - AMI data is only useful if you know building type and size; had to develop ways to assign metadata that avoid privacy concerns
  - Developed process for removing outliers (e.g., misclassified building types, missing meters)
  - AMI sample size can be small – can't rely on AMI alone
  - Will be adding comparisons to additional data sources (e.g. CBECS)
- Making model improvements in parallel, much work still to do
- Region 3 of 4 to finish in May 2021, Region 4 of 4 to finish in August 2021

2 Sets of Weather Data = 2 Sets of EULPs

Typical Meteorological Year (TMY3)

- Widely accepted/expected by utilities, regulators, etc.
- Weather is not coordinated across regions

	Weather Data from Year	
Month	Denver, CO	Boulder, CO
January	1995	1987
February	1994	1990
March	1991	1981
April	1999	1986

Actual Meteorological Year (AMY)

- Using 2018 NOAA data

2 locations 40 miles apart use data from different years for the same month

Format:

- CSV timeseries data for each location used
  - Dry bulb temperature
  - Relative humidity
  - Solar direct normal irradiation
  - Solar diffuse horizontal irradiation
  - Wind speed
  - Building characteristics
- Location used for each Model

Project Outcomes | Working List of End Uses

Commercial

- HVAC
  - Heating
  - Cooling
  - Fans
  - Pumps
  - Heat rejection
  - Humidification
  - Heat recovery
- Service water heating
- Refrigeration
- Plug and process loads
- Lighting
  - Interior
  - Exterior

Residential

- HVAC
  - Heating
  - Cooling
  - Furnace/Air-conditioning
  - Boiler pumps
  - Ventilation fans
- Domestic water heating
- Major appliances
  - Refrigerator
  - Clothes washer
  - Clothes dryer
  - Dishwasher
  - Cooking range
  - Pool/spa pumps & heaters
- Miscellaneous plug loads
- Lighting
  - Interior
  - Exterior

Project Outcomes | Working List of Building Types

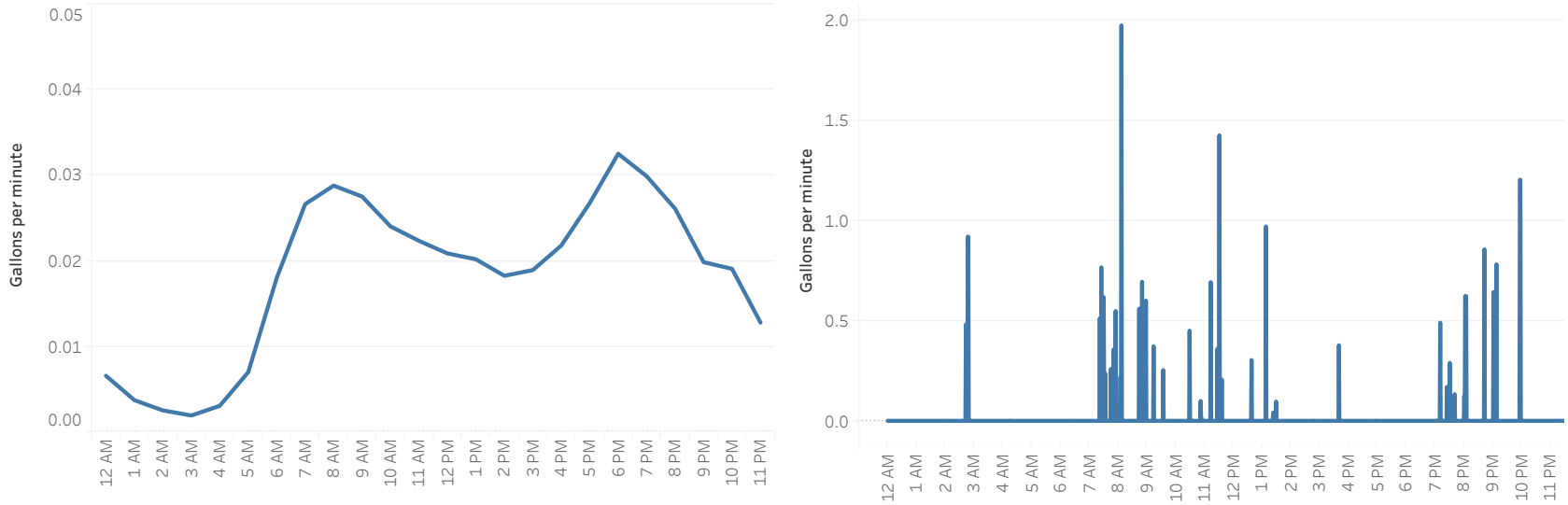
Commercial

- Small Office
- Medium Office
- Large Office
- Stand-alone Retail
- Strip Mall
- Primary School
- Secondary School
- Outpatient Healthcare
- Hospital
- Small Hotel
- Large Hotel
- Warehouse (non-ref.)
- Quick Service Restaurant
- Full Service Restaurant

Residential

- Single-Family Detached
- Single-Family Attached
- Multifamily Low-Rise
- Multifamily Mid-Rise
- Multifamily High-Rise

Project Outcomes| Aggregate and Individual Load Profiles



Example aggregate versus individual EULP concept demonstration using water draws

Use Cases | Data Fidelity Requirements

Time Resolution

15-minute

- Highest impact cases require only hourly results
- PV Planning is the only top use case that requires less than 15-minute data

Geographic Resolution

~~**Utility territory**~~
County

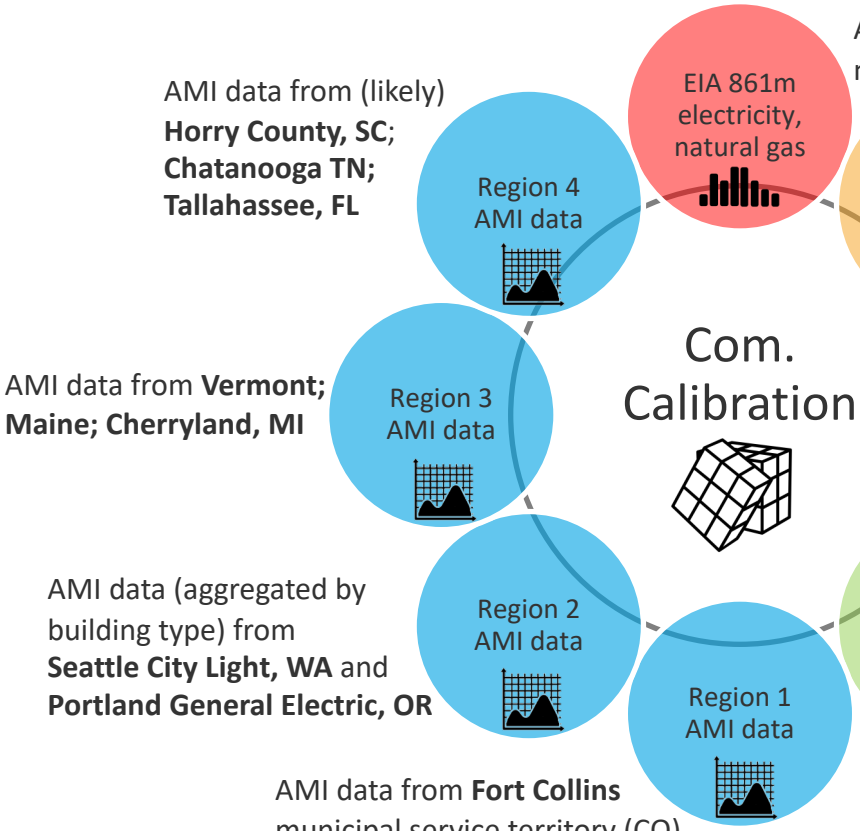
- Distribution System Planning requires feeder-level data
- A “mix-and-match” approach from a bank of load profiles could help build specific utility and feeder level information

Electrical Characteristics

Real power

- Some distribution system planning use cases might benefit from reactive power
- Data requirements for some use cases are not well understood

Commercial Calibration Dimensions



Annual and monthly electricity and natural gas consumption by state, sector

Annual gas and electricity EUIs by building type

Sub-metered end-use load data (10 datasets)

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

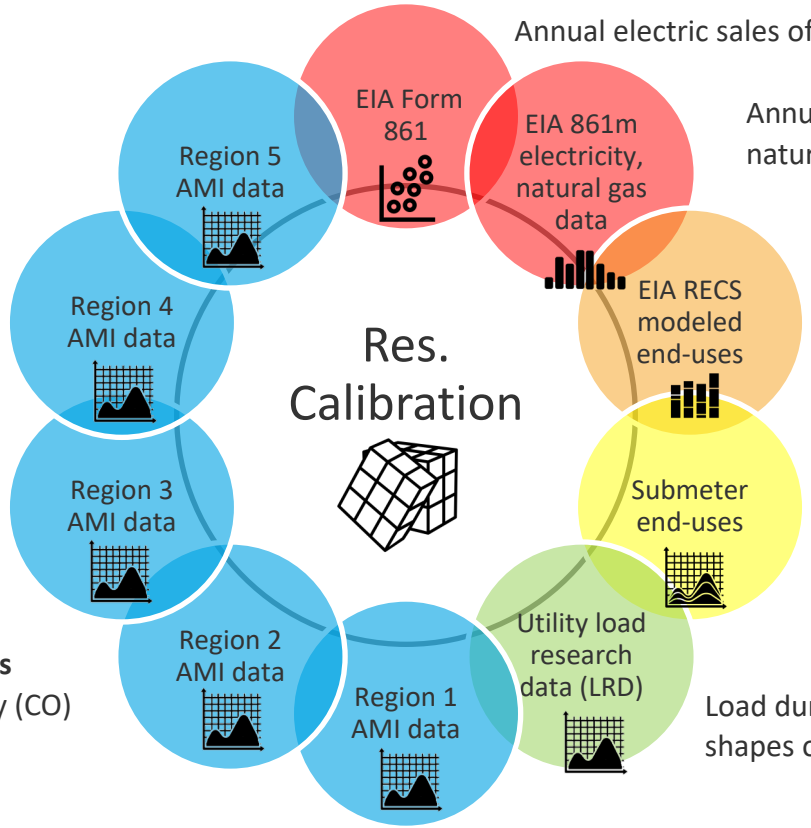
AMI data from (likely) **Horry County, SC**; **Chatanooga TN; Tallahassee, FL**

AMI data from **Vermont; Maine; Cherryland, MI**

AMI data (aggregated by building type) from **Seattle City Light, WA** and **Portland General Electric, OR**

AMI data from **Fort Collins** municipal service territory (CO)

Residential Calibration Dimensions



Annual electric sales of all utilities in U.S.

Annual and monthly electricity and natural gas consumption by state, sector

Annual end-use loads of occupied dwelling units
- Building type
- Climate zone
- Fuel (electricity, natural gas, propane, fuel oil)

Sub-metered end-use load data (5 datasets)

Load duration curves and seasonal load shapes of ~16 utilities around U.S.

Advanced metering infrastructure (AMI) data from **ComEd** service territory (IL)

AMI data from **Fort Collins** municipal service territory (CO)

AMI data (aggregated by building type) from **Seattle City Light, WA**

AMI data from Electric Power Board of **Chattanooga, TN Horry Electric (SC),** and City of **Tallahassee, FL**

AMI data from **Vermont; Cherryland, MI**

Residential end-use transferability study

Residential end use transferability

Question: Are residential end use patterns the same across regions?

- Navigant Massachusetts Residential Baseline Study **(Mass Res 1)**
  - **356 sites,** metered between May 2017 and April 2018
  - **Massachusetts**, representative sample
- NEEA Residential Building Stock Assessment: Metering Study **(RBSAM)**
  - **101 homes,** metered from 2012-04-01 to 2014-07-31
  - **Pacific Northwest**, representative sample
- Florida Solar Energy Center - Phased Deep Retrofit Study **(FSEC)**
  - **56 homes,** metered from 2012 to 2016
  - Central Florida, biased sample
- Pecan Street Dataport **(Pecan Street)**
  - **998 homes,** metered between 2011 to 2014
  - **Texas** (97%), biased sample
- American Time Use Survey **(ATUS)**
  - **~55,000** respondents from 2013–2017 (one day of activities per respondent)
  - National, representative sample

Comparing ATUS to end-use datasets